NEW PERSPECTIVES ON THE POPIGAI IMPACT STRUCTURE. J. B. Garvin[1] and A. L. Deino[2], [1]NASA/Goddard, Geodynamics, Code 921, Greenbelt, MD 20771, USA, [2]Geochronology Center of the Institute of Human Origins, 2453 Ridge Road, Berkeley CA 94709, USA.

The record of large-scale cratering on Earth is scant, and the only currently "proven" 100-km-class impact structure known to have formed within the Cenozoic is Popigai, located in the Siberian Arctic at 71.5°N, 111°E (Masaitis et al., 1975). Popigai is clearly a multiringed impact basin formed within the crystalline shield rocks (Anabar) and platform sediments of the Siberian taiga, and estimates of the volume of preserved impact melt (i.e., Masaitis and Mashchak, 1986) typically exceed 1700 km^3, which is within a factor of 2–3 of what would be predicted using scaling relationships (Melosh, 1989; Grieve and Pesonen, 1992). In this report, we present the preliminary results of an analysis of the present-day topography of the Popigai structure, together with refined absolute age estimates, in order to reconstruct the pre-erosional morphology of the basin, as well as to quantify the erosion or sediment infill rates in the Popigai region.

We have assembled an ~90-m-resolution digital elevation model (DEM) data for the Popigai region (see Fig. 1 for cross sections derived from the 2-D DEM), and are in the process of attempting to reconcile absolute age discrepancies that have resulted from $^{40}Ar/^{39}Ar$ radiometric analyses of glass samples provided to U.S. and Canadian investigators over the past five years by Russian impact crater specialists such as V. Masaitis (VSEGEI/St. Petersburg). In 1991 (see *LPSC XXII*, pp. 297–298), we reported on $^{40}Ar/^{39}Ar$ laser step-heating ages of glass fragments removed from suevite (melt breccia) from the interior cavity of Popigai (provided by V. Masaitis), and obtained ages in the ~70–60-Ma range. We now have preliminary results from the $^{40}Ar/^{39}Ar$ step-heating of six additional glass samples from suevite and allogenic breccia from Popigai (again

TABLE 1. Volumetric analysis of craters.

Crater Name	Diameter (km)	Age (Ma)	Model Interior Volume (km³)	Volume of Excavation (km³)	Model Melt Volume (km³)	Observed Interior Volume (km³)	Max Depth to Melting (km³)	Model Kinetic Energy (Megatone)
Henbury	0.20	0.0040	4.00E-04	2.40E-04	3.00E-08	?	0.011	1.00E-02
Wolf Creek	0.94	0.1000	4.20E-02	2.50E-02	6.00E-04	?	0.065	1.90E+00
Darwin	1.00	0.7300	5.10E-02	3.00E-02	7.00E-04	?	0.070	2.40E+00
Barringer	1.20	0.0490	8.90E-02	5.20E-02	1.30E-03	0.105	0.086	4.50E+00
Goat Paddock	5.00	55.0000	4.13E+00	7.30E+00	1.67E-01	?	0.431	5.78E+02
Bosumtwi	10.50	1.3000	2.28E+01	4.91E+01	2.08E+00	16.100	1.000	7.20E+03
Zhamanshin	14.40	0.8700	4.71E+01	1.08E+02	6.07E+00	20.100	1.400	2.10E+04
Gosses Bluff	22.00	142.0000	1.25E+02	3.18E+02	2.57E+01	?	2.300	8.90E+04
Popigai*	100.00	34.0000	4.06E+03	1.51E+04	4.42E+03	1300.000	12.700	1.53E+07

*Age discrepancy: other age is 66 Ma (K/T).

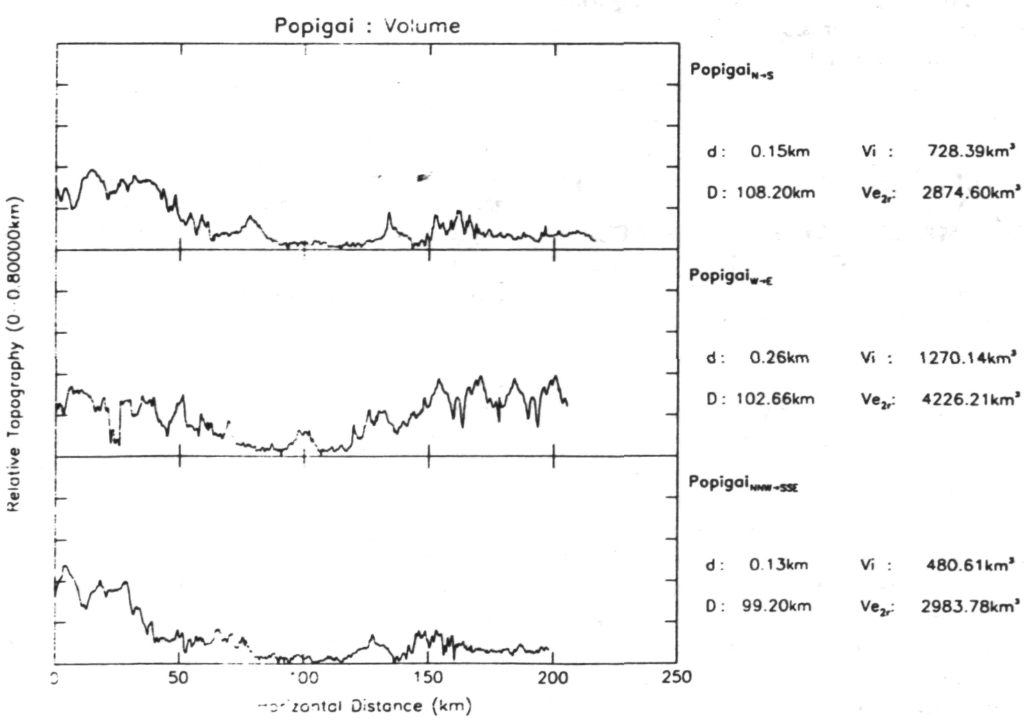

Fig. 1.

provided courtesy of V. Masaitis). Data analysis is still underway, but it is evident that none of the new samples are as well-behaved in age release patterns as was the original sample, due most likely to alteration and the presence of old target-rock mineral inclusions. Predominant ages in these spectra are commonly between ~60 and 40 Ma, but portions of the gas release in the ~40–30 range are also observed. We draw no conclusions as to the age of the Popigai impact event from these data at this early stage. Planned chemical, hydrogen, and oxygen isotopic analyses may help us sort out the effect alteration has had on the Ar age systematics. It is curious to note that independent results of $^{40}Ar/^{39}Ar$ laser step-heating of other samples conducted by Bottomley, Grieve, and York (R. Grieve, personal communication, 1992) indicate well-behaved release patterns that suggest an age in the vicinity of ~34 Ma (Eocene-Oligocene boundary). At this point, our impression is that a combination of analyses of pristine melt glasses and unaltered mineral phases is recommended in order to resolve the age disparity that apparently exists with respect to the absolute age of the Popigai impact.

Using the high-resolution topography data illustrated in Fig. 1, we can attempt to reconstruct the initial crater geometry by means of standard dimensional scaling relationships, such as those summarized in Melosh (1989) and by Grieve and Pesonen (1992). Table 1 highlights some of the parameter values derived for Popigai in comparison with a small set of representative smaller terrestrial features. The maximum degree of original relief at the crater (floor to rim crest) is between 520 and 960 m (depending on the model chosen), while the present-day dynamic range of relief is 260–408 m. This suggests that between 260 and 552 m of relief has been lost due to slumping, erosion, and other processes (interior cavity sediment infill). If we adopt typical erosion models for high-latitude shield terrains (see Garvin and Schnetzler, this volume), we find that up to 0.0052 mm/yr could be eroded at Popigai, which translates into ~176 m over a 34-Ma lifetime, or 350 m over a 66-Ma lifetime. Clearly, a refined absolute age for the structure is needed to refine these erosion estimates; however, the suggestion is that Popigai has experienced up to a factor of 5 more erosional infill than the much smaller equatorial shield crater Bosumtwi. (We acknowledge the cooperation of V. Masaitis at the VSEGEI in St. Petersburg for providing us with Popigai glass samples on several occasions).

THE ZHAMANSHIN IMPACT FEATURE: A NEW CLASS OF COMPLEX CRATER? J. B. Garvin[1] and C. C. Schnetzler[2], [1]NASA/GSFC, Geodynamics Branch, Code 921, Greenbelt MD 20771, USA, [2]Department of Geography, University of Maryland, College Park MD 20742, USA.

The record of 10-km-scale impact events of Quaternary age includes only two "proven" impact structures: the Zhamanshin Impact Feature (ZIF) and the Bosumtwi Impact Crater (BIC). What makes these impact landforms interesting from the standpoint of recent Earth history is their almost total lack of morphologic similarity, in spite of similar absolute ages and dimensions. The BIC resembles pristine complex craters on the Moon to first order (i.e., "U"-shaped topographic cross section with preserved rim), while the ZIF displays virtually none of the typical morphologic elements of a 13- to 14-km-diameter complex crater. Indeed, this apparent lack of a craterlike surficial topographic expression initially led Soviet geologists [1] to conclude that the structure was only 5.5 to 6 km in diameter and at least 4.5 Ma in age [1,10]. However, more recent drilling and geophysical observations at the ZIF have indicated that its pre-erosional diameter is at least 13.5 km, and that its age is most probably 0.87 Ma [2,3,7,9,15]. Why the present topographic expression of a 13.5-km complex impact crater less than 1 m.y. old most closely resembles heavily degraded Mesozoic shield craters such as Lappajarvi is a question of considerable debate [6,7,9–11]. Hypotheses for the lack of a clearly defined craterlike form at the ZIF include a highly oblique impact, a low-strength "cometary" projectile, weak or water-saturated target materials, and anomalous erosion patterns [1,2,6,7,9]. The problem remains unresolved because typical erosion rates within the arid sedimentary platform environment [3] of central Kazakhstan in which the ZIF is located are typically low (see Table 1); it would require at least a factor of 10 greater erosion at the ZIF in order to degrade the near-rim ejecta typical of a 13.5-km complex crater by hundreds of meters in only 0.87 Ma, and to partially infill an inner cavity with 27 km^3 (an equivalent uniform thickness of infill of 166 m). Our analysis of the degree of erosion and infill at the ZIF calls for rates in the 0.19 to 0.38 mm/yr range over the lifetime of the landform, which are a factor of 10 to 20 in excess of typical rates for the Kazakhstan semidesert [3]. If we apply similar erosional models to the BIC, which is located in an equatorial crystalline shield region

TABLE 1. Observed and model parameters for the ZIF and the BIC as derived from analysis of topography and scaling relationships.

Parameter	Zhamanshin	Bosumtwi	Ref.
Age (Ma = 10^6 yr)	0.87	1.3	[2,14]
Apparent diam. Da (km)	14.4	10.5	Meas.
Apparent depth da (km)	0.182	0.300	"
Observed aspect da/Da	0.013	0.030	"
Obs. Ht. Rim Ejecta hej (m)	30.3	83.0	"
Obs. Vol. Cavity Vcav (km^3)	20.1 (max)	16.05	"
Obs. Vcav/SAcav (km)	0.018	0.201	"
Obs. Vol. Ejecta Vej (km^3)	16.7	11.6	"
Obs. Tej = Vej/SAej (km)	0.041	0.049	"
ΔV lost = Vcav–Vej (km^3)	3.4	4.45	"
Tejlost = ΔV lost/SAej (m)	8.3	18.6	"
EJER = Tejlost/Age (mm/yr)	0.0095	0.014	"
Model Vol. Init. Vi (km^3)	47.1	22.8	Comp.
Model Vol. Excav. Vex (km^3)	107.9	48.2	"
Model init. depth di (km)	0.436	0.384	"
Model Aspect di/Da	0.030	0.037	"
Model Vi/SAi (km)	0.289	0.263	"
Model hej* (m)	360.0	263.0	"
her = hej*–hej (m)	329.7	180.0	"
ERIM = her/Age (mm/yr)	0.38	0.14	"
Δ Z = di–da (km)	0.254	0.084	"
Δ Vol. = |Vi–Vcav| (km^3)	27.0	6.75	"
Ter = Δ Vol./SA (km)	0.166	0.078	"
CER = ΔV/SA/Age (mm/yr)	0.19	0.060	"
ΔZ/Age (mm/yr)	0.29	0.065	"
Erosion Model for Target	$\kappa\ \Delta Z^{0.94}$	$\kappa\ \Delta Z^{1.34}$	[3]
κ in Erosion Model	1.05E-4	4.25E-7	[3]
Erosion (mm/yr) @ ΔZ in m	0.019	0.00016	Comp.
Erosion (m) for Crater Age	16.5	0.21	"
Max. Vol. Eroded (km^3)	2.7	0.018	"